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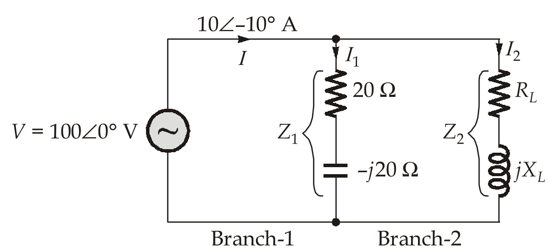
Detailed Solutions

SSC-JE 2018 Mains Test Series (PAPER-II)

Electrical Engineering Test No : 3

Q.1 (a) Solution:

Redrawing the network:



Current through branch-1 is given by,

$$I_1 = \frac{V}{Z_1} = \frac{100\angle 0^\circ}{20 - j20} = \frac{100\angle 0^\circ}{28.28\angle -45^\circ} = 3.54\angle +45^\circ \text{ A}$$

∴ Current in branch-2 is given by,

$$I_2 = I - I_1 = 10\angle -10^\circ - 3.54\angle +45^\circ$$

$$= (9.85 - j1.74) - (2.5 + j2.5) = (7.35 - j4.24) \text{ A}$$

$$= 8.48\angle -30^\circ \text{ A}$$

However, $$I_2 = \frac{V}{Z_2} = \frac{100 + j0}{R_L + jX_L}$$

∴ $$(R_L + jX_L) = \frac{100\angle 0^\circ}{8.48\angle -30^\circ} = 11.8\angle 30^\circ = (10.22 + j5.9)\ \Omega$$

By equating the imaginary parts, we get,

$$X_L = 5.9\ \Omega$$

Q.1 (b) Solution:

(i) Permanent magnet moving coil meter with centre zero, reads average value.

$$\text{Average value} = \frac{\text{sum of area in one period}}{\text{time for one period}}$$

$$= \frac{(5\times10)-(5\times5)}{15} = \frac{25}{15} = 1.67 \text{ V}$$

For reversal of terminals, meter reads –1.67 V.

(ii) Moving iron voltmeter reads rms value $= \sqrt{\dfrac{(10\times5^2)+[(-5)^2\times5]}{15}} = 5 \text{ V}$

meter reads same for reversal of terminals.

Q.1 (c) Solution:

% Full load voltage drop in resistance

$$= \frac{I_2 r_{e2}}{E_2}\times 100 = 2$$

% Full load voltage drop in leakage reactance

$$= \frac{I_2 x_{e2}}{E_2}\times 100 = 4$$

From above $\dfrac{I_2^2\, r_{e2}}{I_2 E_2} = 0.02$

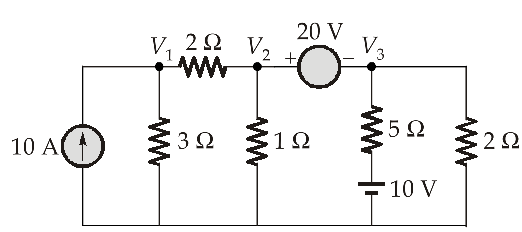
$\therefore$ Full load Cu loss $= 0.02 \times \text{Rated VA}$

$= \text{iron loss(given)}$

Full load $\eta = \dfrac{\text{Rated } VA\times1}{\text{Rated } VA\times1 + I_2^2 r_{e2} + \text{iron loss}}\times100$

$$= \frac{100}{1.04} = 96.154\%$$

Q.1 (d) Solution:



Writing Node equation at Node 1;

$$\frac{V_1}{3} + \frac{V_1 - V_2}{2} = 10$$

$\therefore$ $$0.83\, V_1 - 0.5\, V_2 - 10 = 0 \quad \text{...}(i)$$

Now, writing super-node equation at node 2 and node 3 :

$$\frac{V_2 - V_1}{2} + \frac{V_2}{1} + \frac{V_3 - 10}{5} + \frac{V_3}{2} = 0$$

$$-0.5\, V_1 + 1.5\, V_2 + 0.7\, V_3 - 2 = 0 \quad \text{...(ii)}$$

Also, $$V_2 - V_3 = 20 \quad \text{...(iii)}$$

Solving (i), (ii) and (iii) simultaneously:

$$V_3 = -8.42 \text{ volts}$$

So, current in 5Ω resistor:

$$I_5 = \frac{V_3 - 10}{5} = \frac{-18.42}{5}$$

$\therefore$ $$I_5 = -3.68 \text{ A}$$

Q.1 (e) Solution:

Using two wattmeter method

Reading of wattmeter A = 5000 W

Reading of wattmeter B = –1000 W

$\therefore$ Power factor of the system,

$$\cos\phi = \cos\left[\tan^{-1}\left(\sqrt{3} \times \frac{(W_A - W_B)}{W_A + W_B}\right)\right]$$

$$= \cos\left[\tan^{-1}\left(\sqrt{3} \times \frac{(5000 - (-1000))}{5000 - 1000}\right)\right] = 0.359$$

Q.2 (a) Solution:

$$\text{Transformer efficiency} = \eta = \frac{\text{Output power}}{\text{Input power}}$$

$$= \frac{V_2\, I_2 \cos\phi_2}{V_2\, I_2 \cos\phi_2 + P_c + I_2^2\, r_{e2}} \quad \text{... (i)}$$

where P_c = total core loss, $\cos\phi_2$ = load pf

Condition for maximum efficiency:

In equation (i) P_c is constant and the load voltage V_2 remains practically constant. At a specified value of load p.f. $\cos\phi_2$, the efficiency will be maximum when $\frac{d\eta}{dI_2} = 0$.

Therefore, $\frac{d\eta}{dI_2}$ for Eq. is

$$\frac{d\eta}{dI_2} = \frac{\begin{bmatrix}(V_2 I_2 \cos\phi_2 + P_c + I_2^2 r_{e2})(V_2 \cos\phi_2) \\ -V_2 I_2 \cos\phi_2 (V_2 \cos\phi_2 + 2I_2 r_{e2})\end{bmatrix}}{[V_2 I_2 \cos\phi_2 + P_c + I_2^2 r_{e2}]^2} = 0$$

or $[V_2 I_2 \cos\phi_2 + P_c + I_2^2 r_{e2}] V_2 \cos\phi_2 = V_2 I_2 \cos\phi_2 (V_2 \cos\phi_2 + 2I_2 r_{e2})$

or $$I_2^2 r_{e2} = P_c \qquad \text{... (ii)}$$

or Variable ohmic loss,

$$I_2^2 r_{e2} = \text{Constant core loss, } P_c$$

Hence the maximum efficiency occurs when the variable ohmic loss $I_2^2\ r_{e2}$ is equal to the fixed core loss P_c. From equation (ii) the load current I_2 at which maximum efficiency occurs is given by

$$I_2 = \sqrt{\frac{P_c}{r_{e2}}} = I_{fl}\sqrt{\frac{P_c}{I_{fl}^2 r_{e2}}}$$

If both sides of above equation are multiplied by $E_2/1000$, we get

$$\frac{E_2 I_2}{1000} = \frac{E_2 I_{fl}}{1000}\sqrt{\frac{P_c}{\text{Full load ohmic losses}}}$$

∴ kVA load for maximum,

$$\eta = (\text{rated transformer kVA}) \times \left(\sqrt{\frac{\text{Core loss}}{\text{Ohmic losses at rated current}}}\right)$$

or $$(\text{kVA})_{\max\cdot\eta} = (\text{kVA})\sqrt{\frac{P_c}{I_{fl}^2 r_{e2}}}$$

Q.2 (b) Solution:

Total line parameters are:

$$\text{Resistance, } R = r \times l = 0.15 \times 300 = 45\ \Omega$$

$$\text{Reatance, } X = x \times l = 0.5 \times 300 = 150\ \Omega$$

$$\text{Susceptance, } Y = y \times l = 3 \times 10^{-6} \times 300$$

$$= 9 \times 10^{-4}\ \text{S}$$

For nominal-π equivalent model

(i)

$$A = D = 1+\frac{1}{2}YZ = 1+\frac{1}{2}\times j9\times 10^{-4}\times(45+j150)$$

$$= (0.9325 + j\,0.02025) = 0.9327\angle 1.24°$$

$$B = Z = (45 + j150)\ \Omega = 156.6\ \angle 73.3°\ \Omega$$

$$C = Y\left(1+\frac{1}{4}YZ\right)$$

$$= j9\times 10^{-4}\left[1+\frac{1}{4}\times j9\times 10^{-4}(45+j150)\right]$$

$$= j9\times 10^{-4}\,(0.96625 + j\,0.010125)$$

$$= 8.697\times 10^{-4}\ \angle 90.6°\ \text{S}$$

(ii) Taking receiving-end phase voltage as the reference phasor we have

$$\vec{V}_R = \frac{220}{\sqrt{3}}\times 1000(1+j0) = 127000\ \angle 0°\ \text{V}$$

Load current, $\vec{I}_R = I_R\angle 0°\ \text{A}$

Sending-end phase voltage,

$$\vec{V}_S = A\vec{V}_R + B\vec{I}_R$$

$$= 0.9327\ \angle 1.24°\times 127000\ \angle 0° + 156.6\ \angle 73.3°\times I_R\angle 0°$$

$$= 118{,}425 + j2563 + 45I_R + j150I_R$$

by taking the magnitude,

$$V_S^2 = (118425+45I_R)^2+(2563+150I_R)^2$$

$$\left(\frac{220}{\sqrt{3}}\times 1000\right)^2 = (118425+45I_R)^2+(2563+150I_R)^2$$

or $0.024525I_R^2 + 11.427I_R - 2102 = 0$

by solving the equation, $I_R = 141.175\ \text{A}$

Power received, $P = \sqrt{3}V_{RL}I_R\cos\theta\times 10^{-6}\ \text{MW}$

$$= \sqrt{3}\times 220000\times 141.175\times 1.0\times 10^{-6} = 53.8\ \text{MW}$$

Q.2 (c) Solution:

Given,

$$R_4 = 5\ \Omega$$

$$C_4 = 1\ \text{mF}$$

$$R_2 = 159\ \Omega$$

$$R_3 = 10\ \Omega$$

By using Balance equation,

$$\Rightarrow \quad R_1 = \frac{R_2 R_3}{R_4} = \frac{159 \times 10}{5}$$

$$\therefore \quad R_1 = 318\ \Omega$$

and, $$L_1 = R_2 R_3 C_4$$

$$\therefore \quad L_1 = 159 \times 10 \times 1 \times 10^{-3} = 1.59\ \text{H}$$

$$\Rightarrow \quad \text{Quality factor} = Q = \frac{\omega L_1}{R_1} = \frac{2\pi \times 50 \times 1.59}{318} = 1.57$$

Q.2 (d) Solution:

Merits of Potentiometer:

1. They are inexpensive.
2. They are simple to operate and very useful for applications where the requirements are not particularly severe.
3. They are very useful for measurement of large amplitudes of displacement (in cm scale).
4. Their electrical efficiency is very high and they provide sufficient output to permit control operation without further amplification.
5. It should be understood that while the frequency response of wire wound potentiometers is limited, the other types of potentiometers are free from this problem.
6. In wire wound potentiometers the resolution is limited, while in cermet and metal film potentiometers, the resolution in infinite.

Demerits:

1. The chief disadvantage of using a linear potentiometer is that they require a large force to move their sliding contacts (wipers).
2. The other problems with sliding contacts are that they can be contaminated, can wear out, become misaligned and generate noise. So the life of the transducer is limited. However, recent developments have produced a roller contact wiper which (it is claimed that it) increases the life of the transducer upto 40 times.

Q.3 (a) Solution:

$$\text{Armature circuit resistance} = 500 \times 2 \times 10^{-3} \times \frac{1}{2} = 0.5\ \Omega$$

Let I_f be shunt field current.

The generated emf at 1055 rpm is given by

$$E_{a1} = V_t + (I_L + I_f) \times 0.5 = 100 + (10 + I_f) \times 0.5$$

At 1105 rpm $E_{a2} = 100 + (20 + I_f) \times 0.5$

But $E_{a1} \propto$ field current × speed

and $E_{a1} \propto I_f \times 1055$

$E_{a2} \propto I_f \times 1105$

$\therefore$ $I_f \times 1055 \propto 100 + (10 + I_f) \times 0.5$

and $I_f \times 1105 \propto 100 + (20 + I_f) \times 0.5$

$$\frac{I_f \times 1055}{I_f \times 1105} = \frac{100 + (10 + I_f) \times 0.5}{100 + (20 + I_f) \times 0.5}$$

Its solution gives $I_f = 1$ A.

$\therefore$ $E_{a1} = 100 + (10 + 1) \times 0.5$

$= 105.5$ volts at 1055 rpm

Now $$E_{a1} = \frac{\phi ZnP}{a}$$

or $$105.5 = \frac{\phi \times 1000 \times 1055 \times 2}{60 \times 2}$$

$$\phi = \frac{105.5 \times 60}{1000 \times 1055} = 0.006 \text{ Wb}$$

$\therefore$ Field circuit resistance $= \dfrac{V_t}{I_f} = \dfrac{100}{1} = 100\ \Omega$

Flux per pole = 6 milliweber.

Q.3 (b) Solution:

Working of Thermal Power Plant:

Thermal power plant basically operates on the Rankine cycle. Coal is burnt in a boiler, which converts water into steam. The steam is expanded in a turbine, which produces mechanical power driving the alternator coupled to the turbine. The steam after expansion in prime mover (turbine) is usually condensed in a condenser to be fed into the boiler again. In practice, however, a large number of modifications and improvements have been made so as to affect economy and improve the thermal efficiency of the plant. The entire arrangement divided into four part:

(i) Fuel and ash circuit

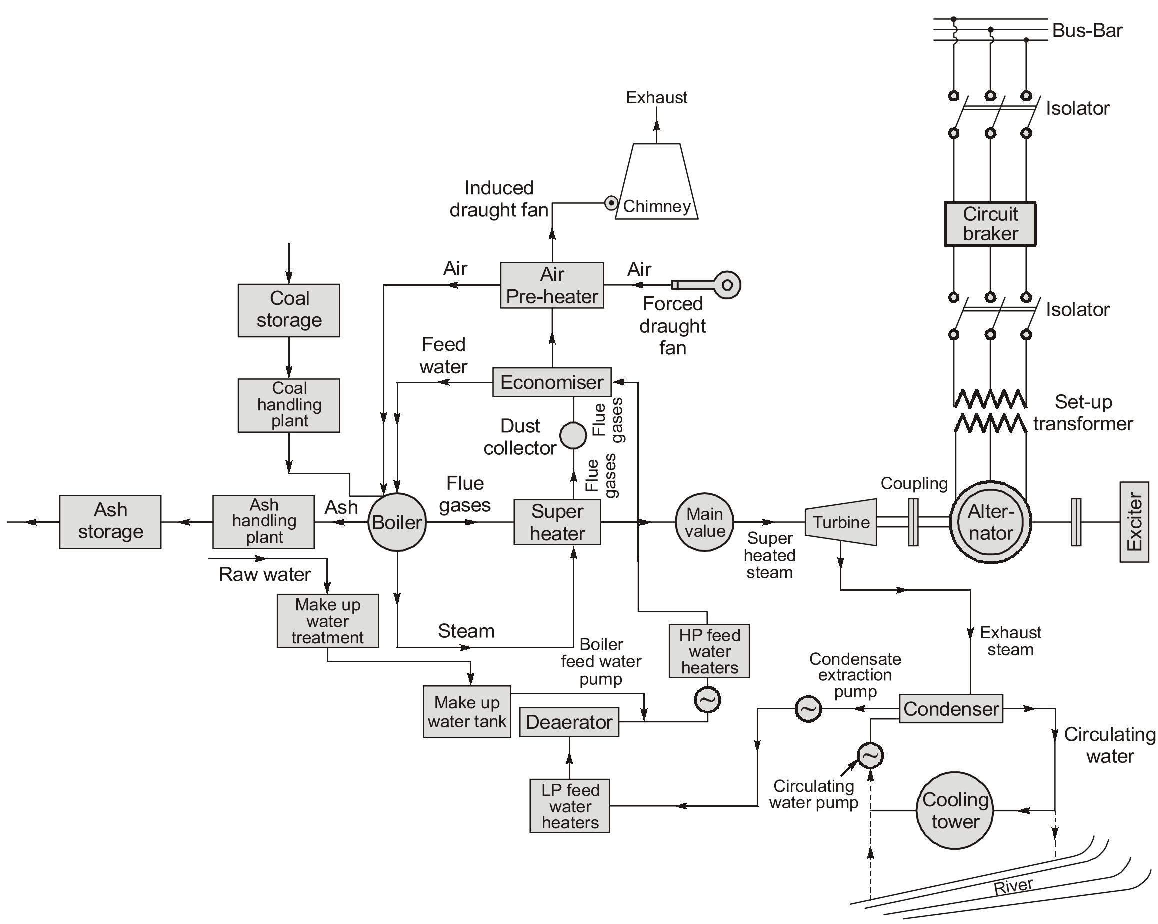
(ii) Air and fuel gas circuit

(iii) Feed water and steam circuit

(iv) Cooling water circuit

(i) **Fuel and Ash Circuit:** The coal is stored in bunkers from where it falls into the hoppers by gravity and finally the requisite quantity of coal either goes on falling directly on the grate, or where the coal spreaders are provided, coal is spread in the grate up to the rear end. When use of spreaders is made, most of the coal burns in air and remaining falls at the rear end of the grate. Any unburnt coal particles in the middle of the grate are collected in a pipe and are again refired by cinder-refiring fan. The ash resulting after complete combustion of fuel collects at the back of the boiler and is removed to the ash storage by means of scrap conveyors.

(ii) **Air and Fuel Gas Circuit:** Air is drawn from the atmosphere by a forced draught fan or induced draught fan through the air perheater, in which it is heated by the heat of flue gases passing to chimney and then admitted to the furnaces. The flue gases after passing around boiler tubes and superheater tubes are drawn by the induced draught fan through dust collector (or precipitator), economizer and air preheater and finally exhausted to atmosphere through chimney.



(iii) **Feed Water and Steam Circuit:** The steam coming out of the turbine is condensed and the condensate is extracted from the condensers by the condensate extraction pump and is forced to the low pressure feed water heaters where its temperature is raised by the heat from bled steam. The feed water is now pumped through deaerator to high pressure feed water heaters, where it gets heated by the heat from bled steam extracted at suitable point of the steam turbine. The function of deaerator is to reduce dissolved oxygen content in the condensate. The water is then pumped into boiler through economiser in which it is further heated by the heat of the flue gases passing through it on the way to chimney. A small part (about 1 percent) of steam and water in passing through the different components of the system is lost. Therefore, water is added in the feed water system as make-up water. In boiler water is converted into high pressure steam, which is wet. Wet steam is passed through superheater, where it is dried and further superheated, and then supplied to the steam turbine through the main valve. After given out its heat energy to the turbine it is exhausted to the condenser where its latent heat is extracted and steam is converted into feed water. At one or more stages a quantity of steam is bled or withdrawn for heating of fed water Making-up water for boiler is taken through the evaporator, where it is heated by low pressure steam extracted at suitable point of turbine.

(iv) **Cooling Water Circuit:** Cooling water is supplied from a natural source of supply such as river, canal, sea or lake or cooling towers through screens to remove the matter, that might choke the condenser tubes. It is circulated through the condenser for condensing the steam and finally discharged to the suitable position near the source of supply. During the passes its temperature rises and in the case of cooling towers the heat must be extracted before the water is again pumped to the condenser. The circulation of cooling water to the condenser help in maintaining a low pressure in the condenser.

Q.3 (c) Solution:

Types of Transmission Lines:

1. Short transmission line
2. Medium transmission line
3. Long transmission line

1. **Short transmission line:** The length of transmission line is lesser than 80 km and operating voltage lower than 20 kV. And product of operating frequency and length of transmission line is less than 4000.

i.e., $l \cdot f < 4000$ (for 50 Hz operation)

Due to smaller distance and lower line voltage, the capacitance effects are small therefore can be neglected.

2. **Medium transmission line:** The length of transmission line in between 80 km and 200 km and line voltage between 20 kV and 100 kV product operating frequency, and length of transmission line is

   i.e., $4000 < l \cdot f < 10000$ (for 50 Hz operation)

   Owing to appreciable length and voltage of the line, the charging current is appreciable and therefore capacitance effect cannot be ignored.

3. **Long transmission line:** The length of transmission line above 200 km and line voltage above 100 kV. Product of operating frequency and length of frequency line is above 10000.

   i.e., $l \cdot f > 10000$ (for 50 Hz operation)

   In these lines impedance and admittance are to be considered uniformly distributed.

Derivation for Voltage Regulation of Short Transmission Line:

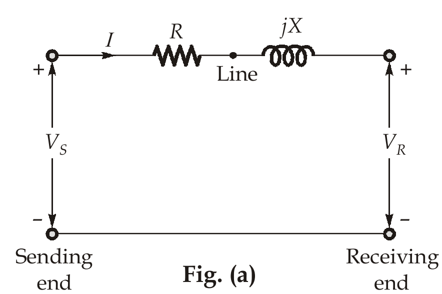


Fig. (a)

From the equivalent circuit shown in figure (a) it is obvious that,

Receiving end voltage,

$$V_R = V_S - I(R + jX) = V_S - IZ$$

Thus quantity IZ is the voltage drop along the line.

Phasor Diagram: Taking phasor I as the reference phasor, for an inductive load (lagging power factor load) is shown in figure (b) where phasor OI, OA, AB, BC, AC and OC represent the load current I, receiving-end voltage V_R, resistive drop IR in line, reactive drop IX in line, line impedance drop IZ and sending-end voltage V_S respectively. From phasor diagram shown in figure (b).

Sending-end voltage,

$$V_S = OC$$

$$= \sqrt{OF^2 + FC^2} = \sqrt{(OD + DF)^2 + (FB + BC)^2}$$

$$= \sqrt{(V_R \cos\phi_R + IR)^2 + (V_R \sin\phi_R + IX)^2}$$

Sending-end phase angle,

$$\phi_S = \tan^{-1}\frac{FC}{OF} = \frac{V_R \sin\phi_R + IX}{V_R \cos\phi_R + IR}$$

and sending-end power factor,

$$\cos\phi_S = \frac{FC}{OF} = \frac{V_R\cos\phi_R + IR}{V_S}$$

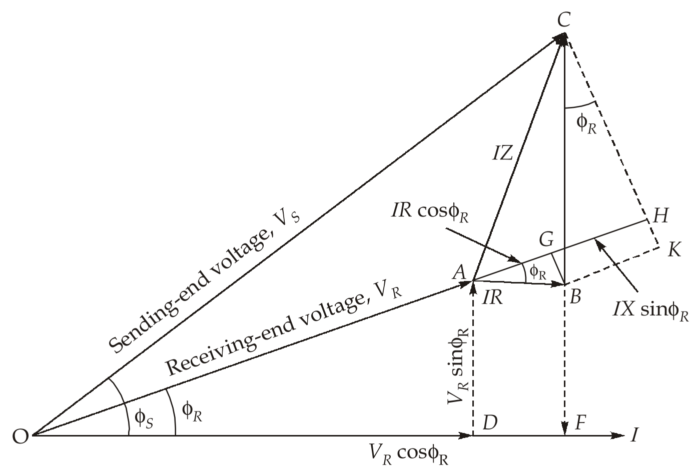


Fig. (b)

$$\text{Percentage voltage regulation} = \frac{V_S - V_R}{V_R}\times 100$$

$$= \frac{\sqrt{(V_R\cos\phi_R + I_R)^2 + (V_R\sin\phi_R + IX)^2} - V_R}{V_R}\times 100$$

For determination of an approximate value of sending-end voltage, V_S may be taken equal to its component along V_R.

So, sending-end voltage, $V_S \simeq OA + AG + GH \simeq V_R + IR\cos\phi_R + IX\sin\phi_R$

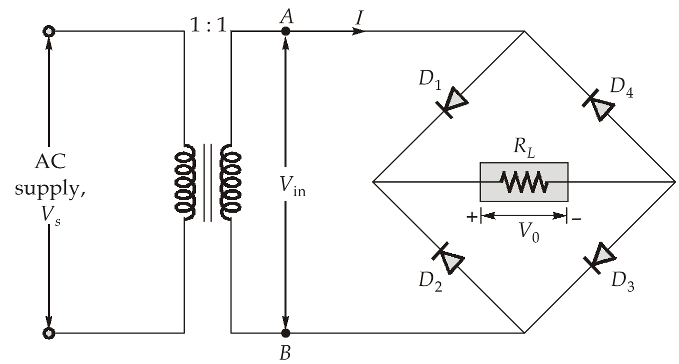
$$\text{Percentage voltage regulation} \simeq \frac{V_S - V_R}{V_R}\times 100\%$$

$$\simeq \frac{V_R + IR\cos\phi_R + IX\sin\phi_R - V_R}{V_R}\times 100\%$$

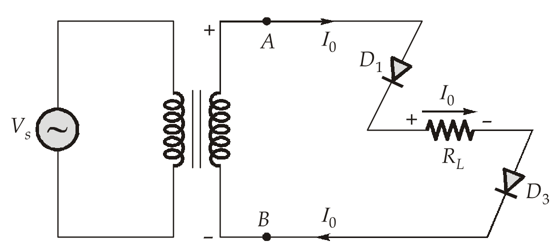
$$\simeq \frac{IR\cos\phi_R + IX\sin\phi_R}{V_R}\times 100\%$$

Q.3 (d) Solution:

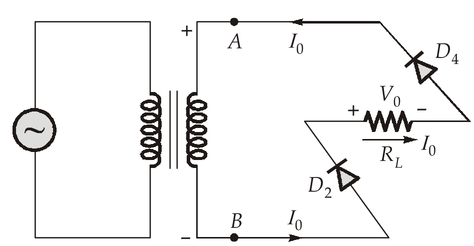
Single-phase Full Bridge Rectifier:



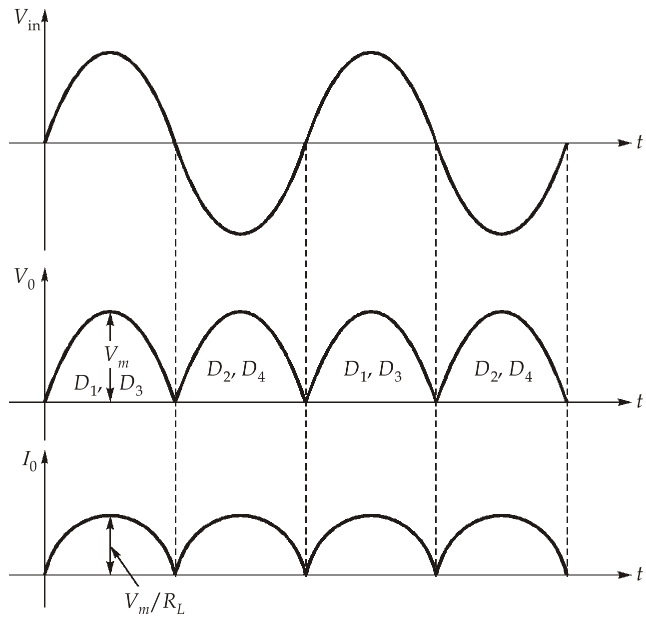
Working: When an ac supply is switched-on, the alternating voltage V_{in} appears across the terminals AB of the secondary winding of the transformer which needs rectification. During the positive half cycle of the secondary voltage, the end A become positive and end B becomes negative. The diode D_1 and D_3 are forward biased and the diodes D_2 and D_4 are reversed biased. Therefore, diode D_1 and D_3 conduct and diode D_2 and D_4 does not conduct. The current (I) flows through diode D_1, load resistor R_L, diode D_3 and the transformer secondary.



During the negative half cycle, the end A becomes negative and end B positive.

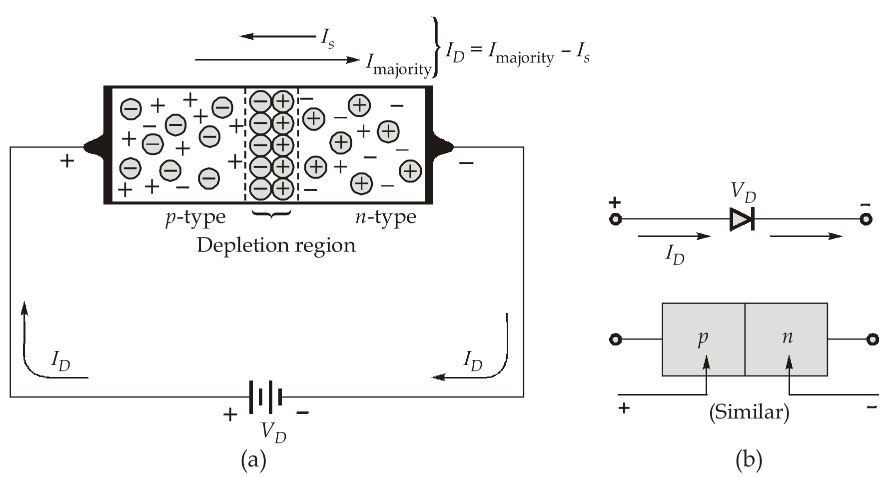


The diode D_2 and D_4 are under forward bias and the diode D_1 and D_3 are reverse bias. Therefore, diode D_2 and D_4 conduct while diode D_1 and D_3 does not conduct. The current (I) flows through the diode D_2, load resistor R_L, diode D_4 and the transformer secondary. The waveform of the single-phase full bridge rectifier.

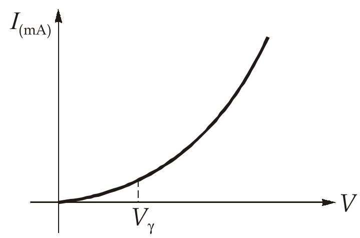


Q.4 (a) Solution:

A forward-bias or "on" condition is established when positive terminal of battery is connected to the *p*-type material and negative terminal to the *n*-type material as shown in figure.



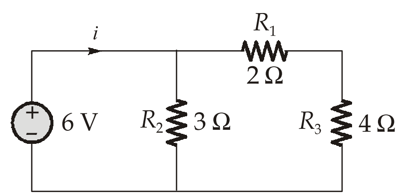
The application of forward-bias potential will "pressure" electrons in the n-type material and holes in the p-type material to recombine with the ions near the boundary and reduce the width of the depletion region as shown in figure. The resulting minority-carrier flow has not changed in magnitude (since the conduction level is controlled primarily by the limited number of impurities in the material), but the reduction in width of depletion region has resulted in a heavy majority flow across the junction. An electron of the *n*-type material now "sees" a reduced barrier at the junction due to the reduced depletion region and a strong attraction for the positive potential applied to the p-type material. As the applied bias increases in magnitude, the depletion region will continue to decrease in width until a flood of electrons can pass through the junction, resulting in an exponential rise in current as shown in the forward-bias region of the characteristics of figure.



V_γ is cut-in voltage (V_r = 0.7 for Si pn diode)

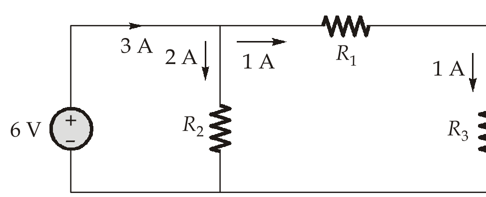
Q.4 (b) Solution:

Considering 6 V voltage source alone, the current source will be open circuited.



$$\Rightarrow \qquad i = \frac{6}{2} = 3\text{ A}$$

according to current division rule.

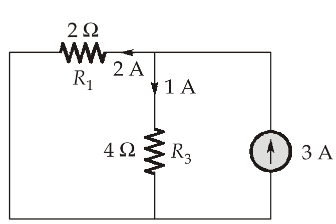


$$I_{R_1} = I_3 \frac{R_2}{(R_1 + R_3) + R_2}$$

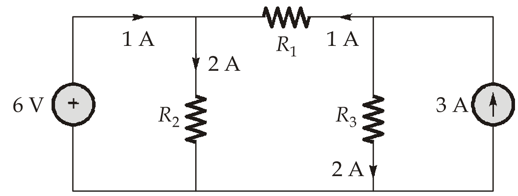
$$I_{R_1} = 1\text{ A}$$

Considering only 3 A current source and short circuiting 6 V voltage source.
According to current division rule

$$I_{R_1} = I_S \times \frac{R_3}{(R_1 + R_3)}$$



Combining the two sources,



$$I_{R_1} = 1\text{ A}$$
$$I_{R_2} = 2\text{ A}$$
$$I_{R_3} = 2\text{ A}$$

Current through the voltage source is 1 A.

Q.4 (c) Solution:

The two alternator operate in parallel should to necessary following conditions:

1. They must have the same output voltage rating.

2. The rated speed of machines should be such as to give same frequency $\left(f = \dfrac{PN}{120}\right)$.

3. The prime-mover of the alternators should have same speed-load characteristics which of course must be drooping ones, so as to load the alternator in proportion to their output ratings.

4. The alternator phase sequence should be same.

5. The alternator should have reactance in their armature.

6. The alternators should generate voltages of the same waveform.

Two or more than two alternators are connected in parallel to a common load due to the following reasons:

(i) **Efficiency:** The load on an electric power station fluctuates during throughout a day since alternators operate most efficiently when operated on full load, it is logical to operate a small unit delivering rated output when load demand is light. If the load increases, a larger unit is substituted for the smaller one or another unit is connected in parallel with one already in operation. This keeps the machines loaded upto their rated capacity and increases the efficiency of operation.

(ii) **Reliability (or continuity are service):** If one unit fails, the continuity of supply can be maintained by the remaining units which connected in parallel otherwise interrupted power supply is interrupted after failure of a unit.

(iii) **Maintenance and Repair:** It considered necessary to carry out regular inspection and maintenance of the machinery so as to avoid the possibility of failure. Repairing of a unit is convenient and economical if there are several small units in the power station. The cost of stand by unit is small.

(iv) Size: Alternators are built in larger size. Hence it be come necessary to operate two or more units in parallel.

Q.4 (d) Solution:

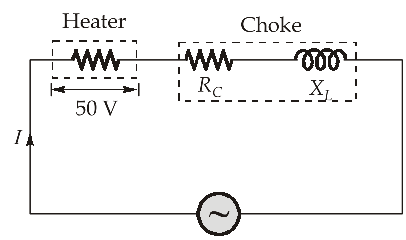
It is given that,

$$I = 10 \text{ A}$$

$$V_H = \text{Drop across the heater} = 50 \text{ V}$$

$$R_C = \text{Resistance of choke} = 5\ \Omega$$

$$V_s = \text{Source voltage} = 200 \text{ V}$$



Here, $R_H = \text{Resistance of Heater} = \frac{50}{10} = 5\ \Omega$

∴ Net resistance of the circuit is,

$$R = R_H + R_C = 5 + 5 = 10\ \Omega$$

∵ The drop across R_H, $V_{RH} = R_H \times I = 5 \times 10 = 50 \text{ V}$

And the drop across choke resistance,

$$V_{RC} = R_C \times I = 50 \text{ V} \quad ...(i)$$

Also, the drop across X_L, the inductive reactance of the choke, can be given as,

$$V_L = IX_L = 10X_L \text{ V} \quad ...(ii)$$

However, the supply voltage being the vector sum of the drops V_R and V_L

∴ $$V_s = \left(V_{RC} + V_{RH}\right) + jV_L$$

$$(200)^2 = (50 + 50)^2 + V_L^2$$

or $$V_L^2 = (200)^2 - (100)^2$$

$$V_L = 173.21 \text{ V} \quad ...(iii)$$

Thus, from equations (ii) and (iii),

$$X_L = \frac{V_L}{I} = \frac{173.21}{10} = 17.321\ \Omega \quad ...(iv)$$

This gives the impedance of the choke as,

$$Z_C = \sqrt{R_C^2 + X_L^2} = \sqrt{5^2 + 17.321^2} = 18.028\ \Omega$$

$\therefore$ The impedance of the whole circuit

$$= \sqrt{(R_C + R_H)^2 + X_L^2}$$

$$Z = \sqrt{(10)^2 + (17.321)^2}$$

$$Z = 20\ \Omega$$

$$\therefore \quad \text{Power factor} = \frac{R}{Z} = \frac{10}{20} = 0.5$$

Q.5 (a) Solution:

$$\text{Slip} = S = \frac{1500 - 1425}{1500} = 0.05$$

$$\therefore \quad \text{Electromagnetic torque} = \frac{P_m}{\omega_s(1-S)}$$

$$T_e(fl) = \frac{10{,}000 \times 60}{2\pi \times 1500(1-0.05)} = 67.013 \text{ Nm}$$

Slip at which maximum torque occurs is given by

$$S_{mt} = \frac{1500 - 1200}{1500} = 0.2$$

$$\therefore \quad \frac{T_e(fl)}{T_{em}} = \frac{67.013}{T_{em}} = \frac{2}{\frac{0.05}{0.2} + \frac{0.2}{0.05}}$$

$$\therefore \quad T_{em} = 142.403 \text{ Nm}$$

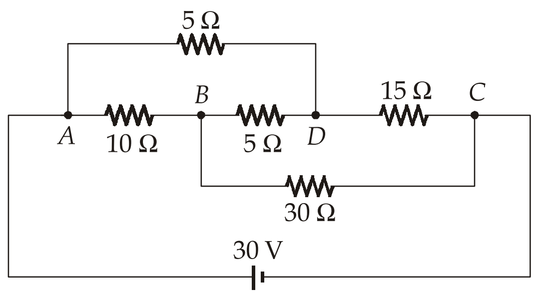
For obtaining starting, use the relation

$$\frac{T_e(st)}{T_{em}} = \frac{2}{\frac{1}{S_{mt}} + \frac{S_{mt}}{1}} = \frac{2}{\frac{1}{0.2} + \frac{0.2}{1}}$$

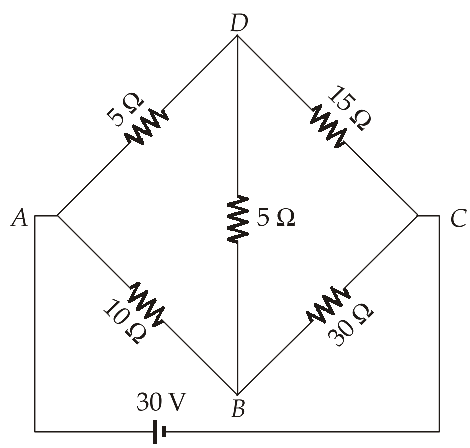
$$\therefore \quad T_e(st) = 0.3846 \times 142.403 = 54.7682 \text{ Nm}$$

Q.5 (b) Solution:

The given circuit can be rearranged as follows:



On rearranging again



Since, $$\frac{R_{AD}}{R_{AB}} = \frac{R_{CD}}{R_{BC}}$$

i.e. $$\frac{5}{10} = \frac{15}{30}$$

∴ The above circuit is a balanced Wheatstone's bridge. Hence, the current through 5 Ω resistor i.e. between B and D is 0.

Q.5 (c) Solution:

Given that: Number of turns, $N = 500$

Resistance of coil $= 4\ \Omega$

Mean diameter of ring $= 0.25$ m

Cross-sectional area of ring,

$$A = 700 \text{ mm}^2 = 700 \times 10^{-6} \text{ m}^2$$

Supply voltage, $V_{DC} = 6$ V

Relative permeability of iron,

$$\mu_r = 500$$

The current flowing in the coil,

$$I = \frac{V_{DC}}{R} = \frac{6}{4} = 1.5 \text{ A}$$

Magnetic field strength, $$H = \frac{NI}{l} = \frac{500 \times 1.5}{l}$$

$\therefore$ $$l = \text{mean circumference}$$
$$= \pi \times \text{mean diameter} = \pi \times 0.25$$

so, $$H = \frac{500 \times 1.5}{\pi \times 0.25} = 954.9296 \text{ A/m}$$

Flux density, $$B = \mu H = \mu_0 \mu_r H$$
$$= 4\pi \times 10^{-7} \times 500 \times 954.9296 = 0.6 \text{ Wb/m}^2$$

Total flux, $$\phi = B.A$$
$$= 0.6 \times 700 \times 10^{-6}$$
$$= 0.42 \times 10^{-3} \text{ wb} = 0.42 \text{ mWb}$$

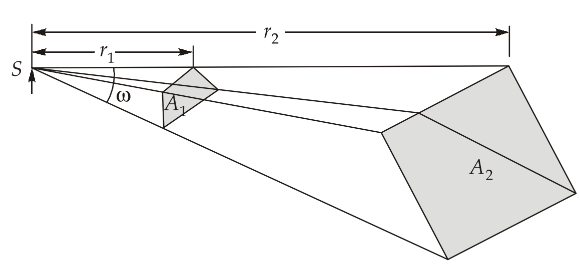
Q.5 (d) Solution:

Laws of Illuminations:

1. Law of inverse squares
2. Lambert's cosine law

1. **Law of Inverse Squares:** The illumination of a surface is inversely proportional to the square of the distance between the surface and the light source provided that the distance between the surface and the source is sufficiently, large so that the source can be regarded as a point source.

or, $$E \propto \frac{1}{r^2}$$



Consider surface area A_1 and surface area A_2 at distances r_1 and r_2 respectively from the source point 'S' of illumination intensity I and normal to the rays. The solid angle subtended be ω steradians. Luminous flux radiated per steradians = I.

Illumination on the surface of area, A_1

$$= \frac{I\omega}{A_1} \text{Lumen/unit area and } A_1 = \omega r_1^2$$

∴ Illumination on the surface of area A_1,

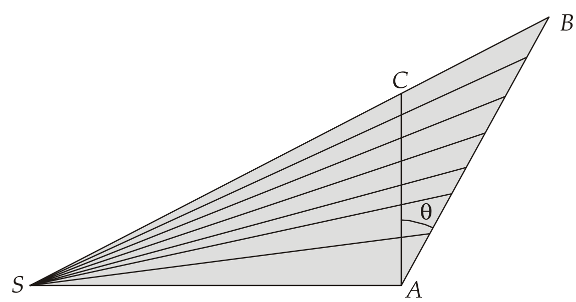
$$E_1 = \frac{I\omega}{A_1} = \frac{I\omega}{\omega r_1^2} = \frac{I}{r_1^2} \text{ Lumens/unit area}$$

Similarly illumination on the surface of area A_2,

$$E_2 = \frac{I\omega}{A_2} = \frac{I\omega}{\omega r_2^2} = \frac{I}{r_2^2} \text{ Lumens/unit area}$$

2. Lambert's Cosine Law:

According to this law the illumination at any point on a surface is proportional to the cosine of the angle between the normal at that point and direction of luminous flux.



Increase ratio: $\dfrac{AB}{AC} = \dfrac{1}{\cos\theta}$

and the illumination decreases in the ratio (decrease ratio) cosθ/1

Illumination, $E = \dfrac{I\cos\theta}{r^2}$

Q.6 (a) Solution:

(i) Welding is a materials joining process. It is the only way to join two or more pieces of metal to make them act as one piece.

Advantage of welding:

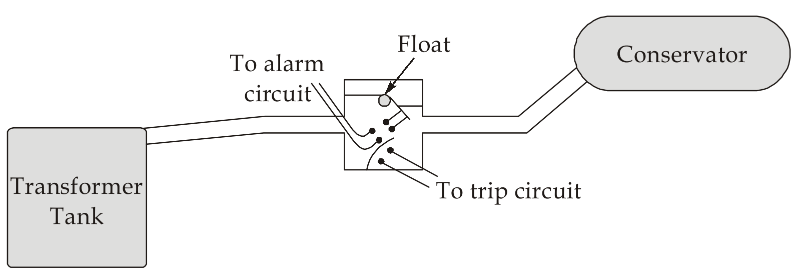
1. Welding is the lowest cost joining method.
2. It affords lighter weight through better utilization of materials.
3. It joins all commercial metals.
4. It can be used anywhere.
5. It provides design flexibility.

The various welding processes used in general engineering are given below:

1. Gas welding:
   (i) Oxyacetylene (ii) Air-acetylene (iii) Oxy-hydrogen
2. Resistance welding:
   (i) Butt (ii) Spot (iii) Projection
   (iv) Seam (v) Percersion
3. Arc welding:
   (i) Carbon arc (ii) Metal arc (iii) Gas metal arc
   (iv) Gas tungsten arc (v) Atomic hydrogen arc (vi) Plasma arc
   (vii) Submerged arc (viii) Flux-cored arc and (ix) Electro-slag
4. Thermit welding
5. Solid state welding:
   (i) Friction (ii) Ultra sonic (iii) Diffusion and (iv) Explosive
6. Newer welding:
   (i) Electron beam and
   (ii) Laser

(ii) Buchholz Relay:

Buchholz relay is a gas actuated relay. It is universely used on all oil immersed transformers having rating more than 500 kVA. Such relay can only be fitted to the transformers equipped with conservator tanks as it is installed in between the conservator tank and the transformer tank.

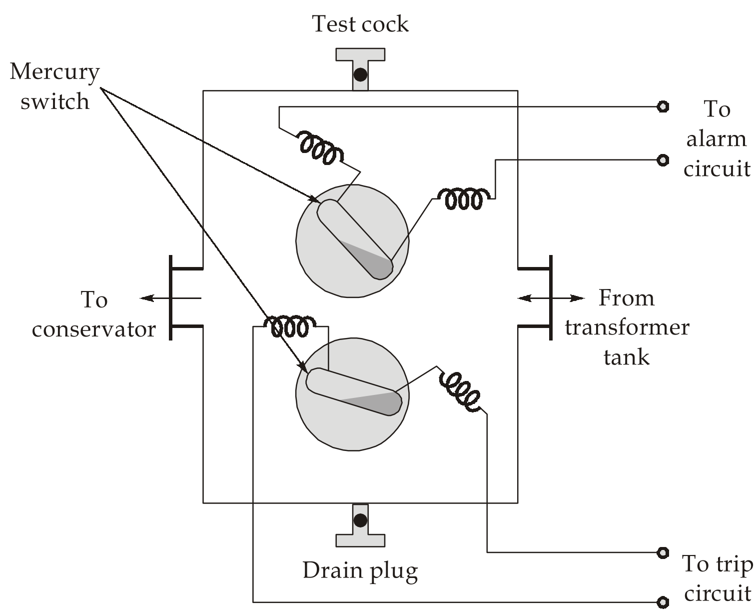


It provides protection only against transformer internal faults and does not respond to external bushing or cable connection faults.

Whenever a fault occurs inside the transformer the oil of the tank gets over heated and gases are generated. The generation of the gases may be slow or violent depending upon whether the fault is a minor or incipient one or heavy short circuit.

It consists of two hinged floats in a metallic chamber located in the pipe connection between the conservator and the transformer tank. One of the floats is near the top of chamber and actuates the mercury switch connected to the external alarm circuit.

The other float is opposite the orifice of the pipe to the transformer and actuates the mercury switch connected to the tripping circuit.

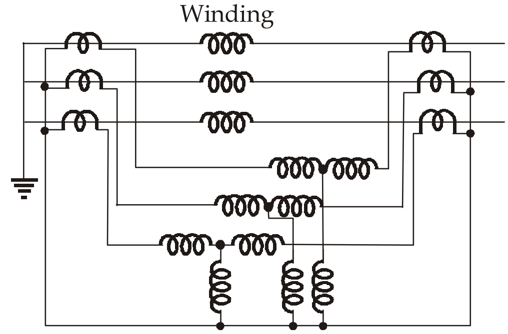


Procetion of transformer using Buchholz relay.

The main advantage of Buchholz relay is that they indicate incipient faults. For example, between turns faults or core heating and so may enable a transformer to be taken out of service before serious damage occurs.

(iii) Merz-Price Protection of Alternator Stator Windings:

This is most commonly used protection scheme for the alternator stator windings. The scheme is also called biased differential protection and percentage differential protection. In this method, the currents at the two ends of the protected section are sensed using current transformers. The wires connecting relay coils to the current transformer secondaries are called pilot wires. Under normal conditions, when there is no fault in the windings, the currents in the pilot wires fed from C.T. secondaries are equal. The differential current $(i_1 - i_2)$ through the operating coils of the relay is zero. Hence the relay is inoperative and system is said to be balanced. When fault occurs inside the protected section of the stator windings, the differential current $(i_1 - i_2)$ flows through the operating coils of the relay. Due to this current, the relay operates. This trips the generators circuit breaker to isolate the faulty section. The is also disconnected and is discharged through a suitable impedance. The figure shows a schematic arrangement of Merz-Price protection scheme for a star connected alternator.



Stator protection Y grounded alternator

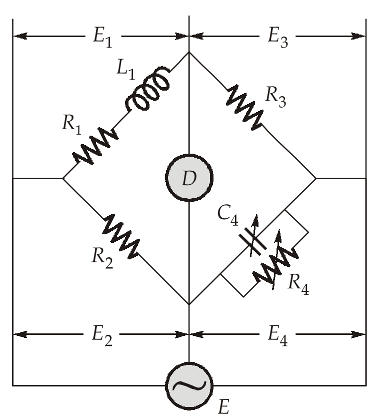
Merz-Price protection for star connected alternator

The differential relay gives protection against short circuit fault in the stator winding of a generator. The C.T.s are connected in star and are provided on both, the outgoing side and machine winding connections to earth side. The restraining coils are energized from the secondary connection of C.T.s in each phase, through pilot wires. The operating coils are energized by the tappings from restraining coils and the C.T. neutral earthing connection.

The advantages of this scheme are:

1. Very high speed operation with operating time of about 15 msec.
2. It allows low fault setting which ensures maximum protection of machine windings.
3. It ensures complete stability under most severe through and external faults.
4. It does not require current transformers with air gaps or special balancing features.

Q.6 (b) Solution:



Maxwell's Inductance–Capacitance bridge

⇒In this bridge, an inductance is measured by comparison with a standard variable capacitance.

Let,

$$L_1 = \text{unknown inductance}$$
$$R_1 = \text{Effective resistance of inductor } L_1$$
$$R_2, R_3, R_4 = \text{Known non-inductive resistances}$$
$$C_4 = \text{Variable standard capacitor}$$

Writing the equation for balance,

$$(R_1 + j\omega L_1)\left(\frac{R_4}{1 + j\omega C_4 R_4}\right) = R_2 R_3$$

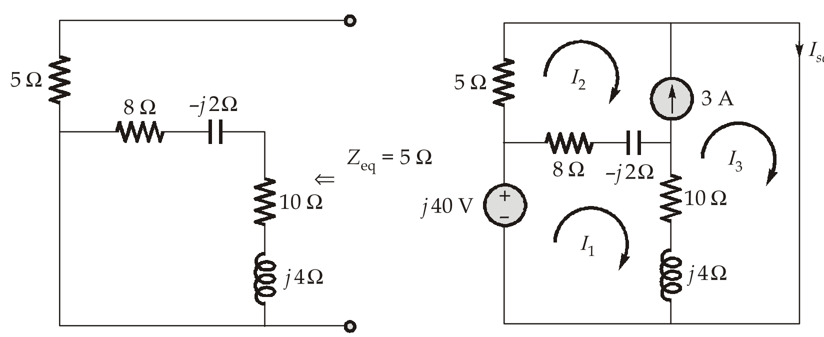
or,
$$R_1 R_4 + j\omega L_1 R_4 = R_2 R_3 + j\omega R_2 R_3 C_4 R_4$$

Separating the real and imaginary terms, we have

$$R_1 = \frac{R_2 R_3}{R_4}$$

and
$$L_1 = R_2 R_3 C_4$$

Q.6 (c) Solution:



Mesh (i) equations,

$-j40 + (18 + j2)\ I_1 - (8 - j2)\ I_2 - (10 + j4) I_3 = 0$ ...(i)

Super mesh equation,

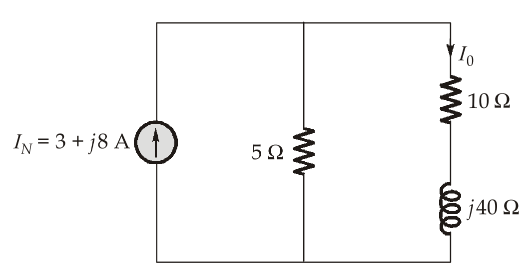
$(13 - j2)\ I_2 + (10 + j4)\ I_3 - (18 + j2)\ I_1 = 0$ ...(ii)

Current source,

$$I_3 = I_2 + 3 \quad \text{...(iii)}$$

From (i) + (ii)

$$-j40 + 5I_2 = 0,$$
$$I_2 = j8\text{A}$$
$$I_3 = I_2 + 3 = (3 + j8)\text{ A}$$



Norton circuit

Norton current

$$I_N = (3 + j8)\text{ A}$$

$$I_0 = \frac{(3+j8)5}{5+10+j40}$$

$$I_0 = \frac{3+j8}{3+j8} = 1\text{ A}$$

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